

# *Friction Noise Caused by Fretting and its Prevention*

*Tatsuhiro Jibiki*

*Tokyo University of Marine  
Science and Technology*



# Background and Aim of this Study

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## Background

- Under the micro reciprocating motion, or micro oscillating motion like "fretting",
  - It may be accompanied by friction noise
  - Preventing or reducing the friction noise could be important for designers, operators, and engineering
- Friction noise generated at the actual machine element
  - Generally grease lubricated, but could not be prevented adequately
  - It's attributable to the mystery of its mechanism (namely, no report)

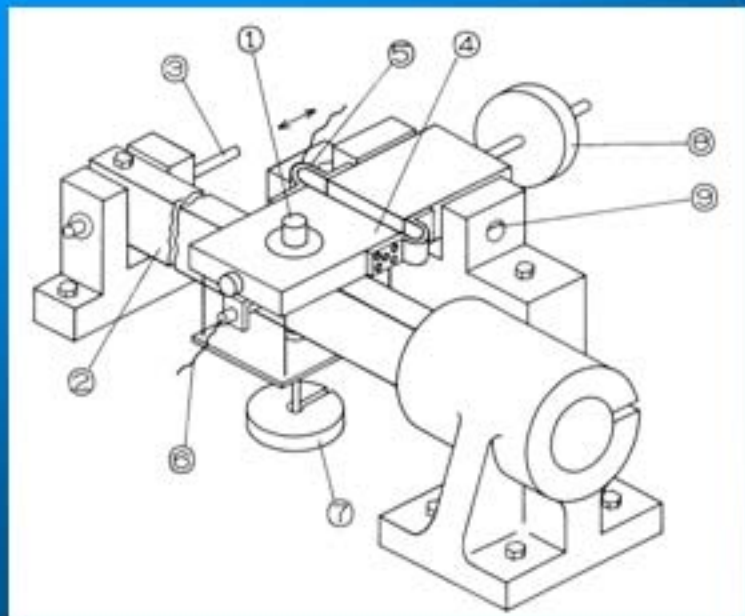
## Aim

1. To clarify the mechanism of the friction noise caused by fretting
2. To get a guideline of its prevention



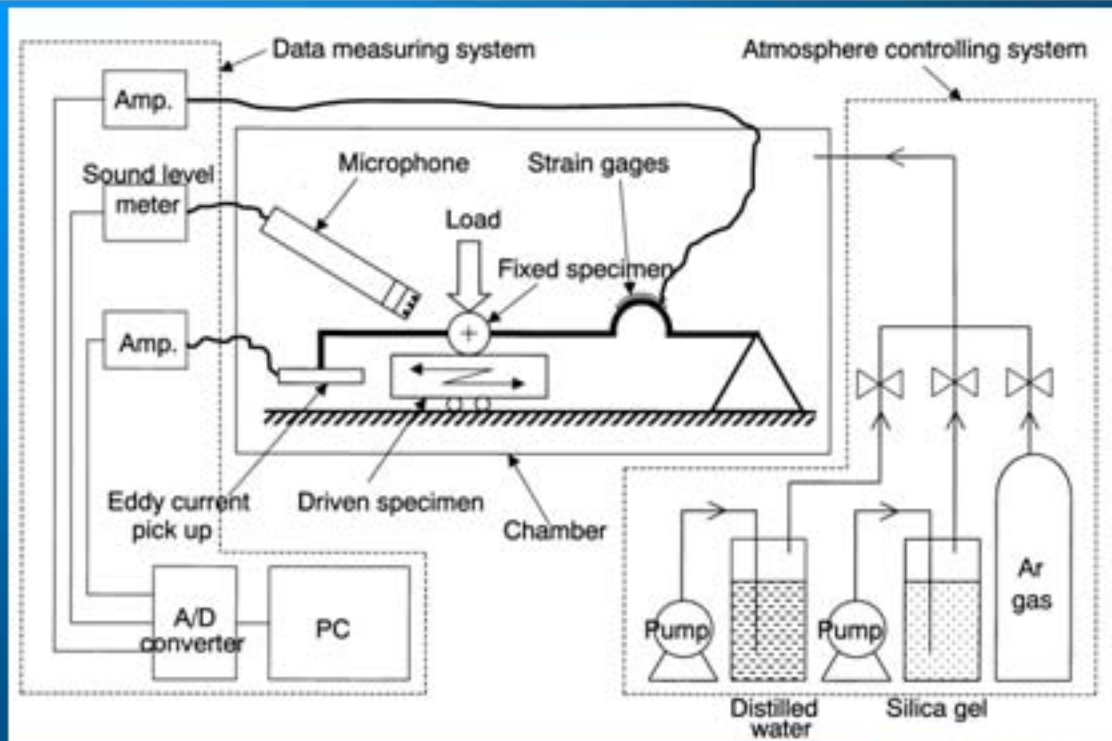


# Overview of fretting wear apparatus



- ① Upper specimen
- ② Cantilever
- ③ Driving arm
- ④ Upper specimen holder
- ⑤ Leaf spring
- ⑥ Eddy current pickup
- ⑦ Dead weight
- ⑧ Counterweight
- ⑨ Anvil

# Apparatus



*Schematic diagram of the fretting rig*





# Test apparatus



# Specimens

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Table Specimens

Fixed specimen (Upper specimen)	0.45% carbon steel quenched Hv730, Ry1.0 $\mu$ m
Driven specimen (Lower specimen)	Mild steel Hv240, Ry1.0 $\mu$ m



# Fretting test

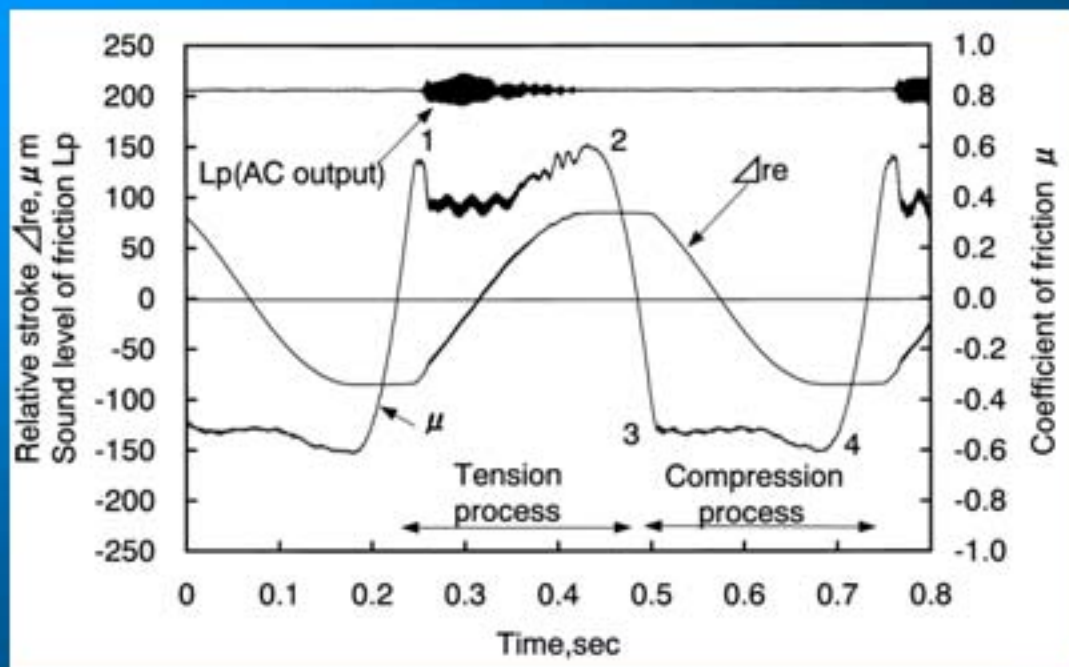
*Table Experimental conditions*

Fretting stroke	25~ 400 $\mu$ m
Normal load	19.6N
Atmosphere	Laboratory air, Grease lubrication
Test duration	Up to $10^6$ cycles
Frequency	7.3Hz
Temperature	$294 \pm 2$ K
Relative humidity	23~ 80% RH
Data sampling frequency	5kHz (4096 data)
Configuration	Crossed cylinders, Ball on plate





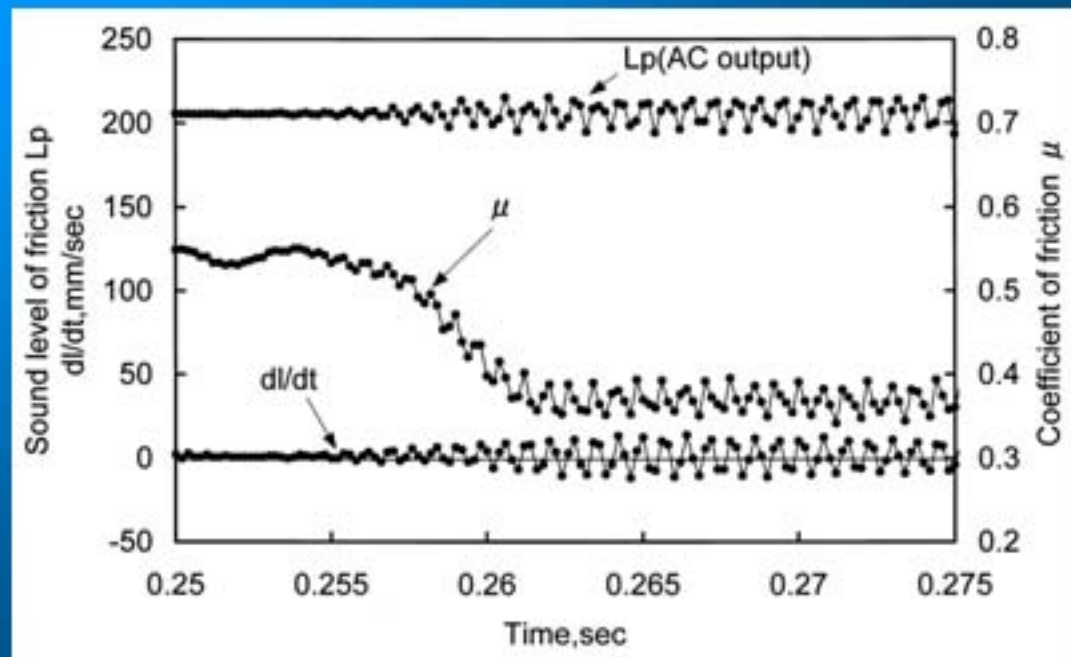
# Measurements and analysis of waveforms



Typical example showing waveforms of friction noise (AC output),

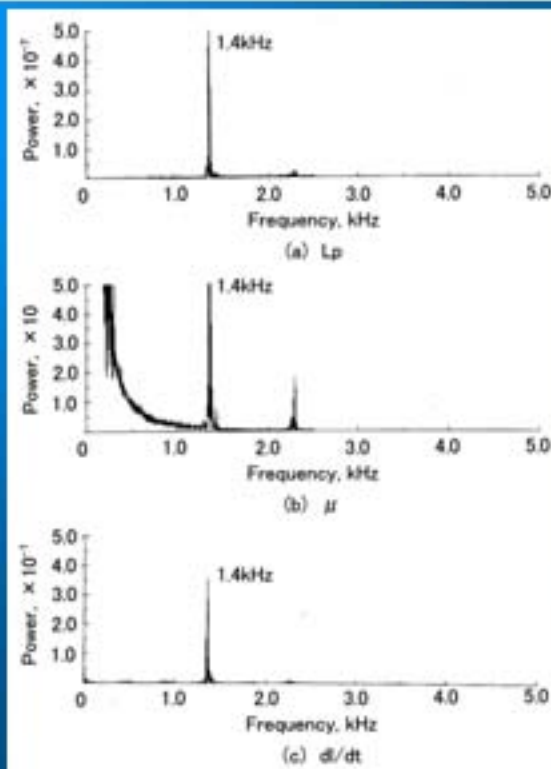
coefficient of friction  $\mu$ , and relative stroke  $\Delta re$

# Measurements and analysis of waveforms



Magnified time axis around the beginning of tension process

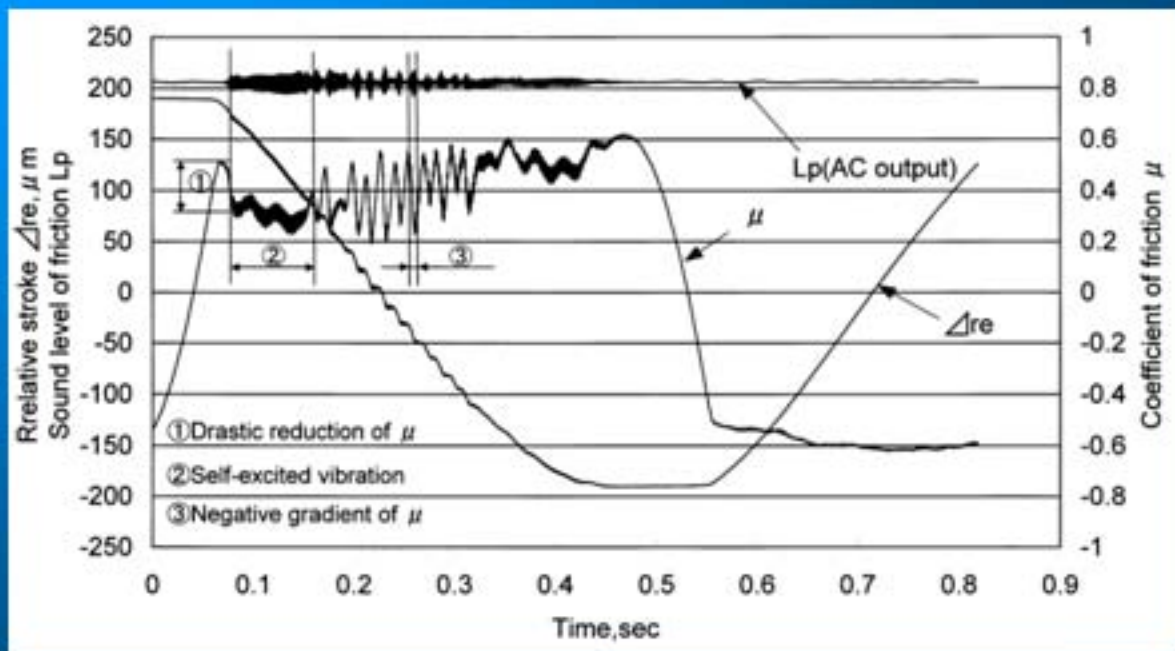
# Measurements and analysis of waveforms



FFT analysis of  $L_p$ ,  $\mu$ , and  $dI/dt$



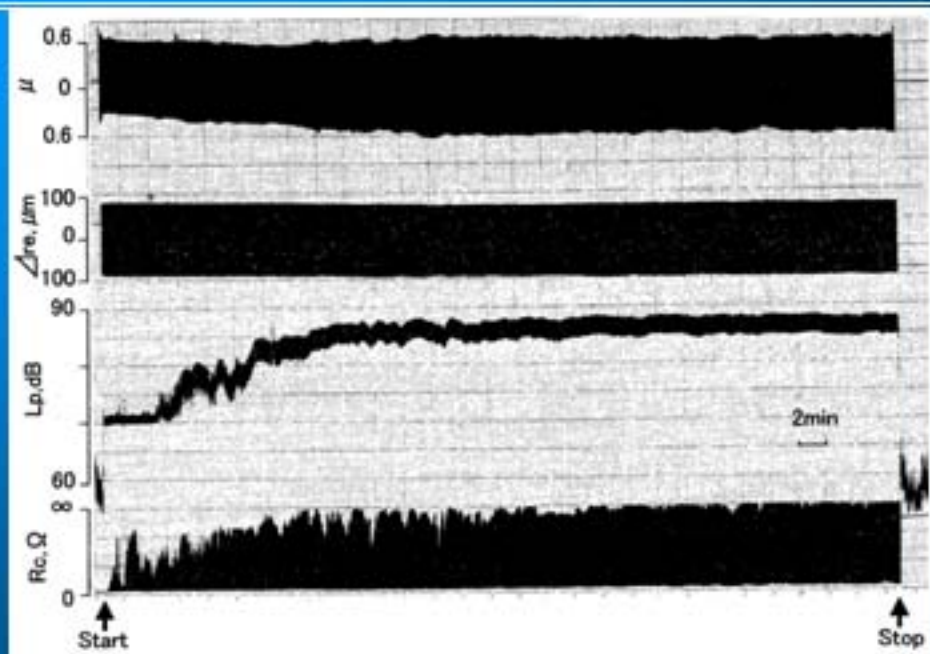
# Measurements and analysis of waveforms



Another typical example of waveforms;

Stroke of  $401 \mu m$ , 30%RH, 1Hz

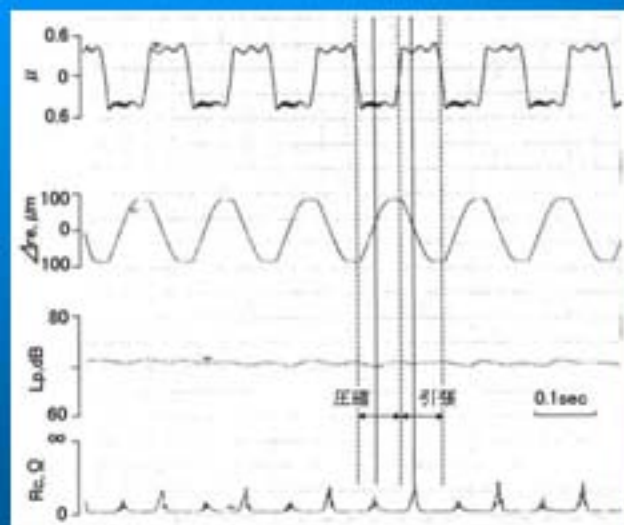
# Measurement of electrical contact resistance $R_c$



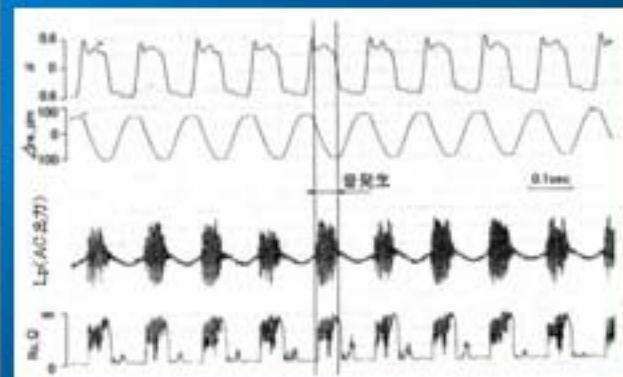
Electrical contact resistance  $R_c$  and friction noise  $Lp$  (DC output) together with  $\mu$  and  $\Delta re$  versus fretting cycles; Stroke of  $191 \mu m$ , 46%RH, 7.2Hz, 25000cycles



# Measurement of electrical contact resistance $R_c$

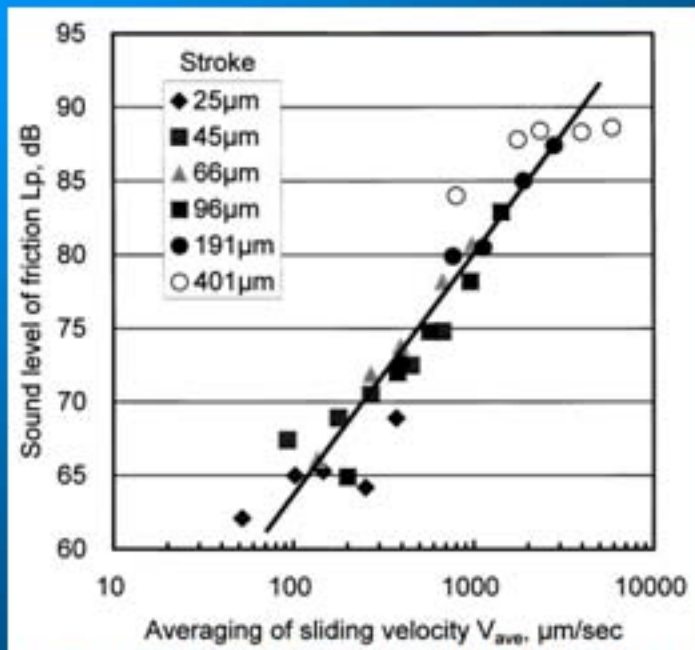


Precise  $R_c$  and  $L_p$  (DC output) before the occurrence of friction noise; after 300 cycles



Precise  $R_c$  and  $L_p$  (AC output) after the occurrence of friction noise; after 25000 cycles

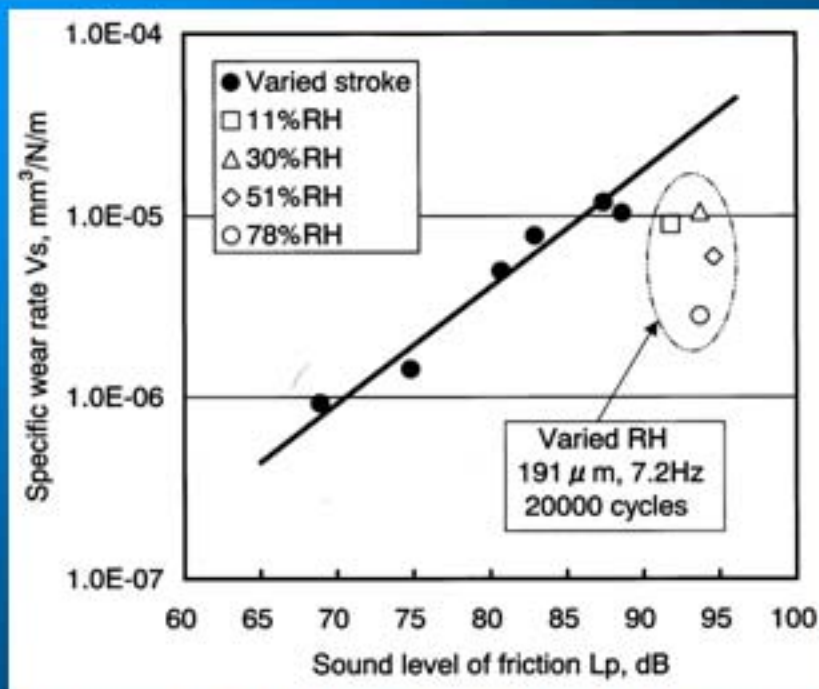
# *Influence of fretting stroke and frequency*



$L_p$  (dB value) plotted against  $V_{ave}$ ; 30% RH, 25000 cycles



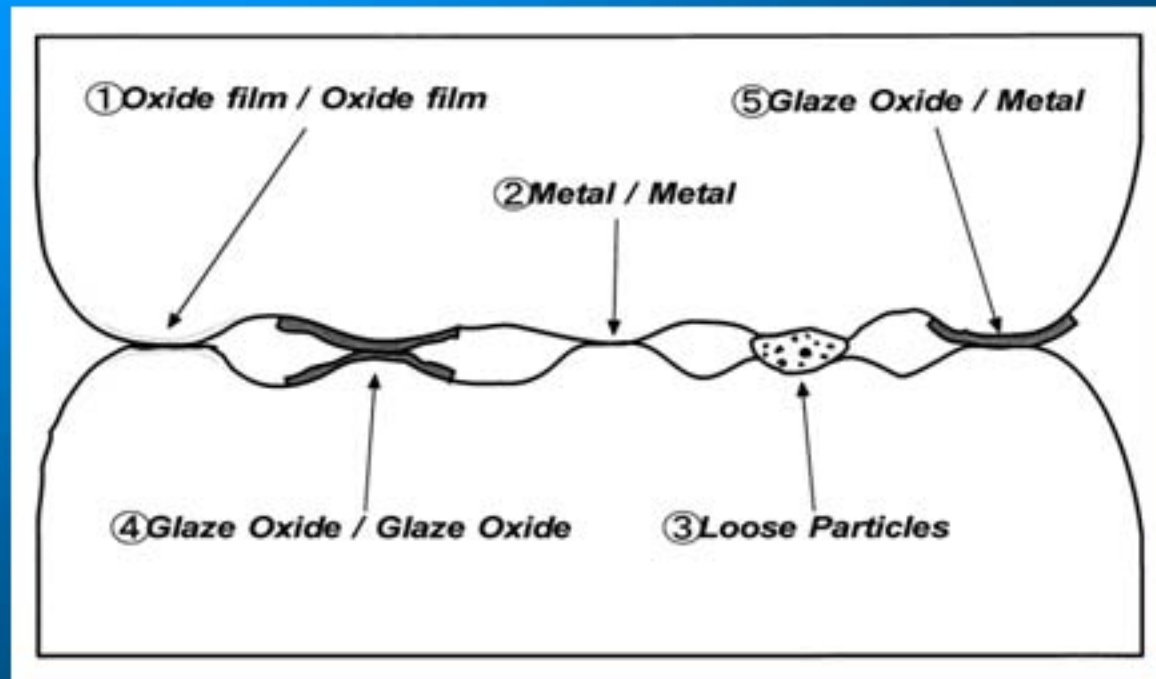
## Specific wear rate Vs and sound level of friction $L_p$



(fretting stroke = 191  $\mu$  m, 7.2 Hz, 25000 cycles)



# Possible mechanism of friction noise



Type of contact point

## *Effect of types of contact point on $\mu$ and Rc*

Type of contact point	$\mu$	Rc
① Oxide film / Oxide film	0.33	Low
② Metal / Metal	1.09	Very low
③ Loose particles	0.69	High
④ Glaze oxide / Glaze oxide	0.83	Low
⑤ Glaze oxide / Metal	0.83	Low





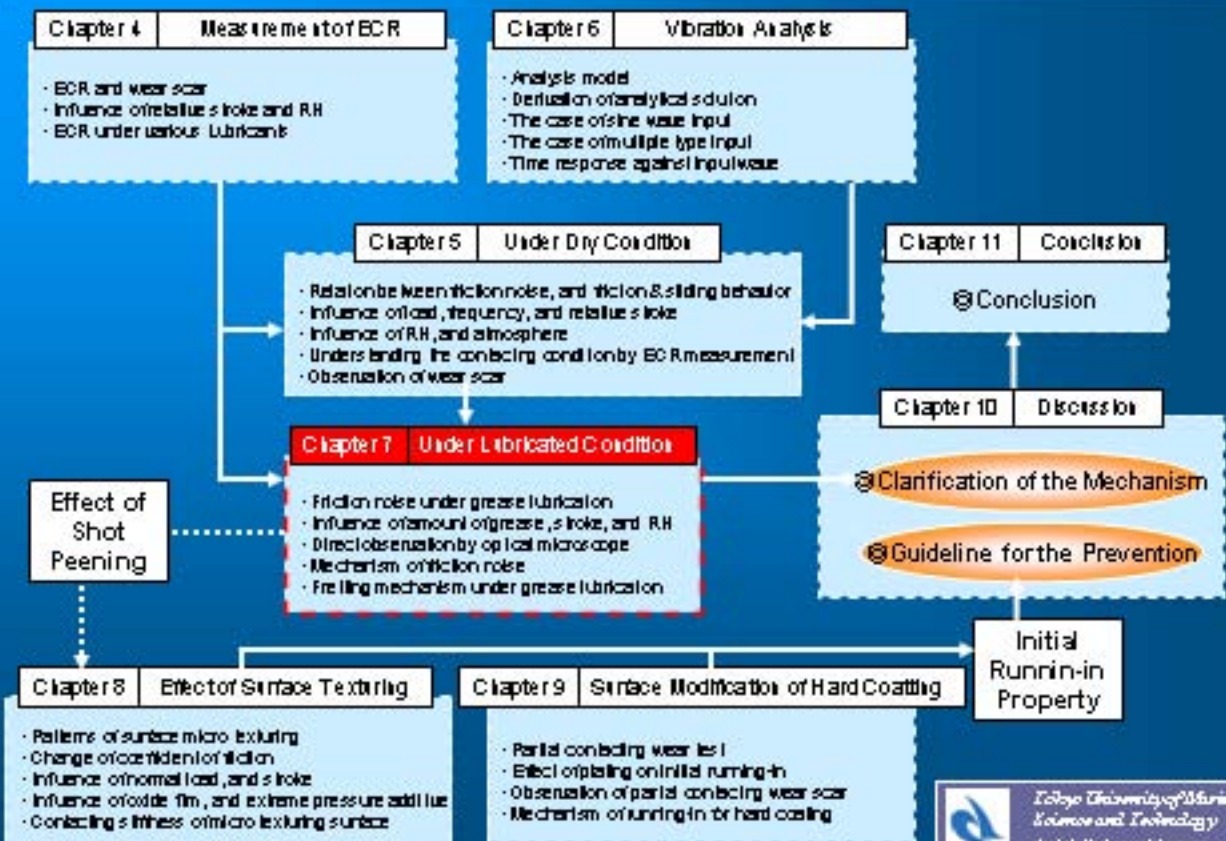
# Brief Conclusions (1)

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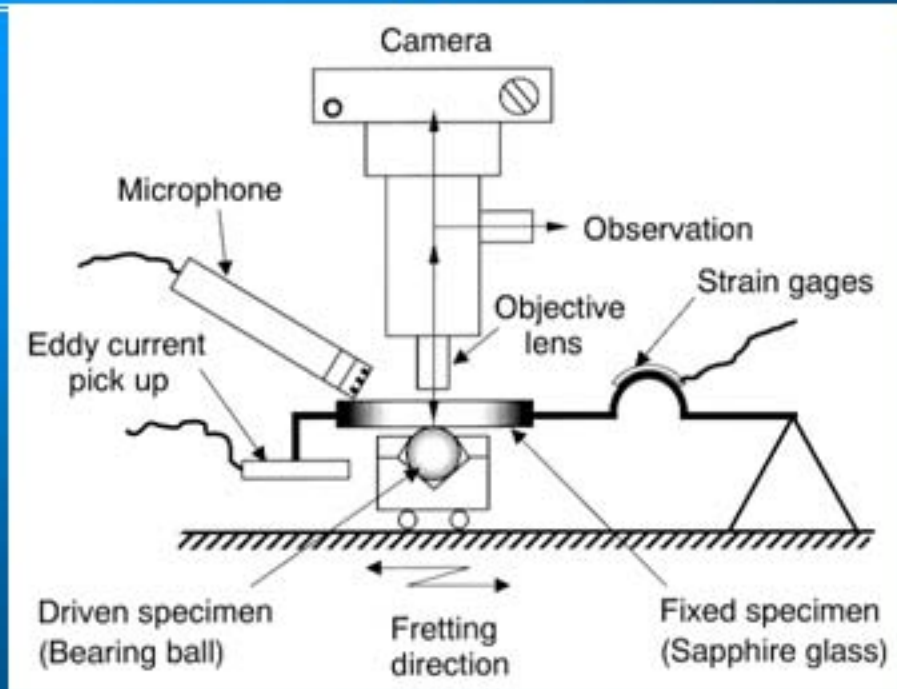
1. Certain cycles of fretting are needed to generate friction noise.
2. There are common features in relation to the occurrence of friction noise : drastic reduction in coefficient of friction  $\mu$  , self-excited vibration and negative gradient of  $\mu$  .
3. Sound level of friction increases with increase in fretting stroke and frequency, and is directly related to average sliding velocity.
4. There is a good relation between the sound level and amount of wear.



# Composition of this Study



# Apparatus



*Schematic illustration of direct observation of fretted area*



# Lubricants

Table Lubricants

Type	Lithium soap grease
Base oil	Mineral oil
Viscosity of base oil	145.4[mm <sup>2</sup> /s]@40°C 14.67[mm <sup>2</sup> /s]@100°C
Consistency	285(25°C,60W)
Additive	MoS <sub>2</sub> powder



# Fretting test

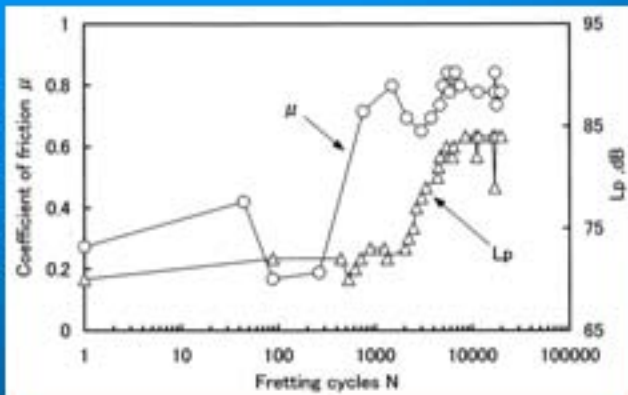
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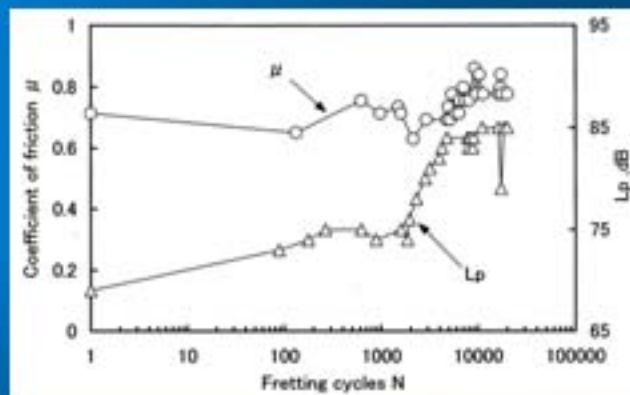




# Typical results of measurements



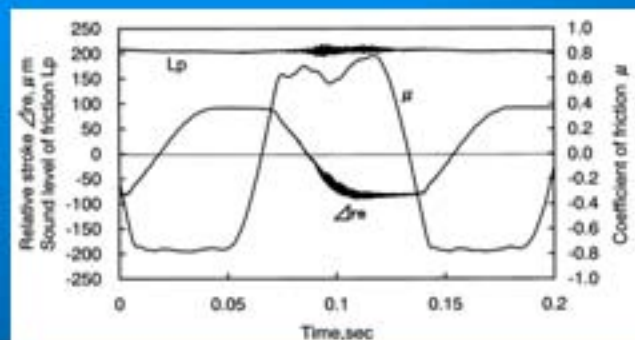
(a)  $S=130 \mu m$ ,  $G=6 \mu m$



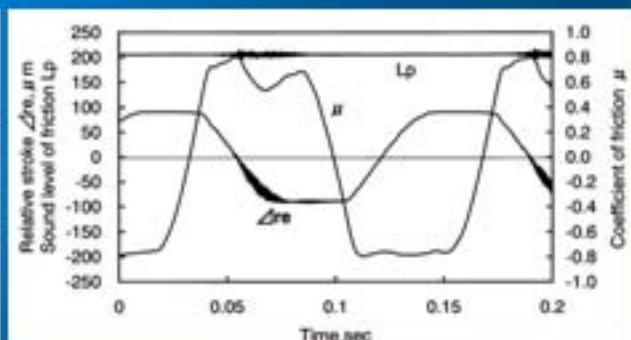
(b)  $S=130 \mu m$ ,  $G=0 \mu m$

$\mu$  and  $L_p$  plotted against fretting cycles  $N$

# Typical results of measurements



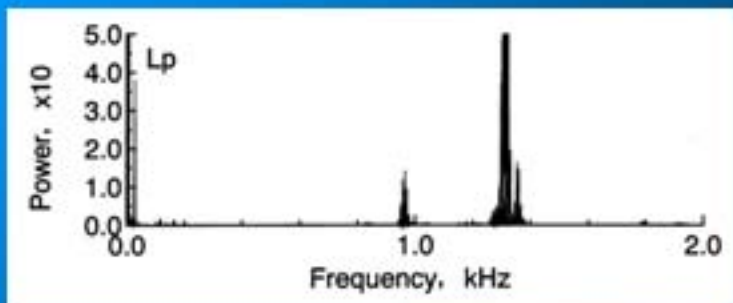
(a)  $S=130 \mu m$ ,  $G=6 \mu m$ ,  
 $N=5000$  cycles



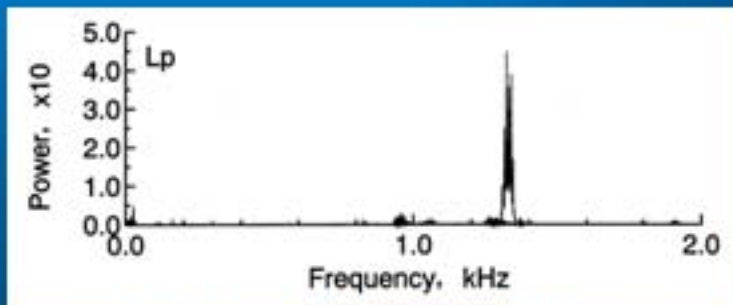
(b)  $S=130 \mu m$ ,  $G=0 \mu m$ ,  
 $N=5000$  cycles

Curves of  $Lp$ ,  $\mu$ , and  $\Delta re$

## Typical results of measurements



(a)  $S=130\ \mu m$ ,  $G=6\ \mu m$ ,  $N=5000$  cycles

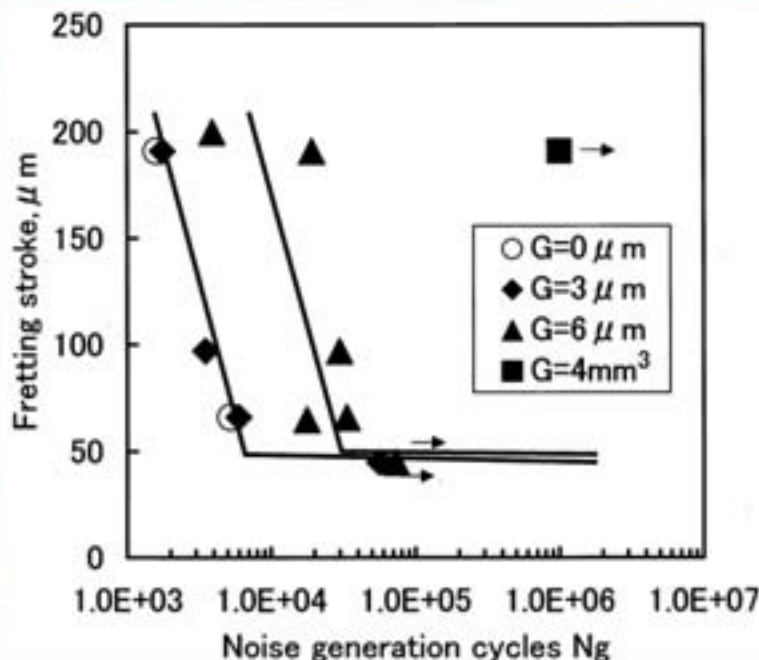


(b)  $S=130\ \mu m$ ,  $G=0\ \mu m$ ,  $N=5000$  cycles

FFT analysis of  $L_p$  and  $dI/dt$



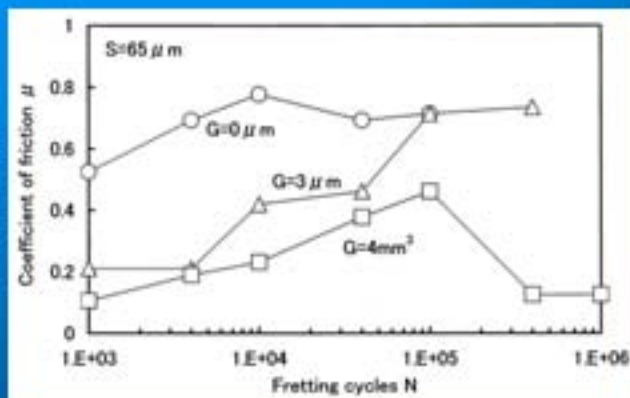
## Typical results of measurements



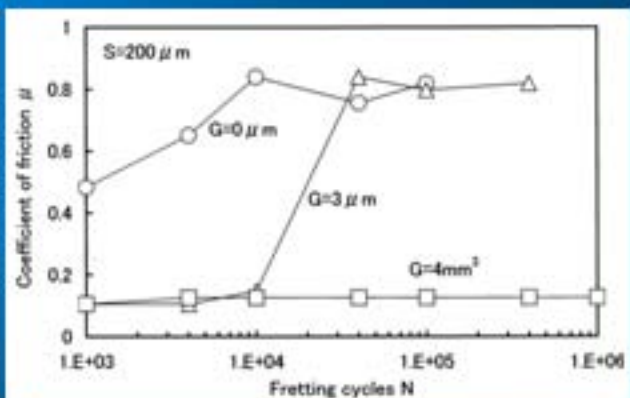
*Influence of the amount of grease and fretting stroke on the noise generation cycles  $N_g$*



# Typical results of measurements



(a)  $S=65 \mu m$



(b)  $S=200 \mu m$

Relationship between  $\mu$  and  $N$



# Typical results of measurements



(i)  $10^3$  cycles



(i)  $10^3$  cycles



(i)  $10^3$  cycles



(ii)  $10^4$  cycles



(ii)  $10^4$  cycles



(ii)  $10^4$  cycles



(iii)  $10^5$  cycles  
(a)  $G=0 \mu m$



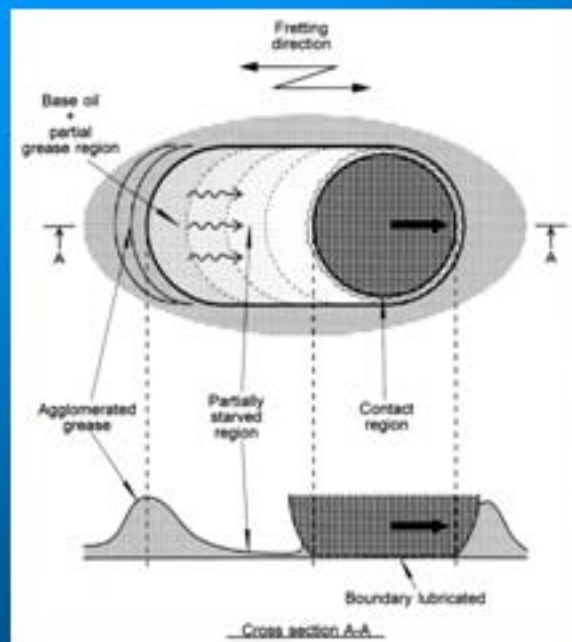
(iii)  $10^5$  cycles  
(b)  $G=3 \mu m$



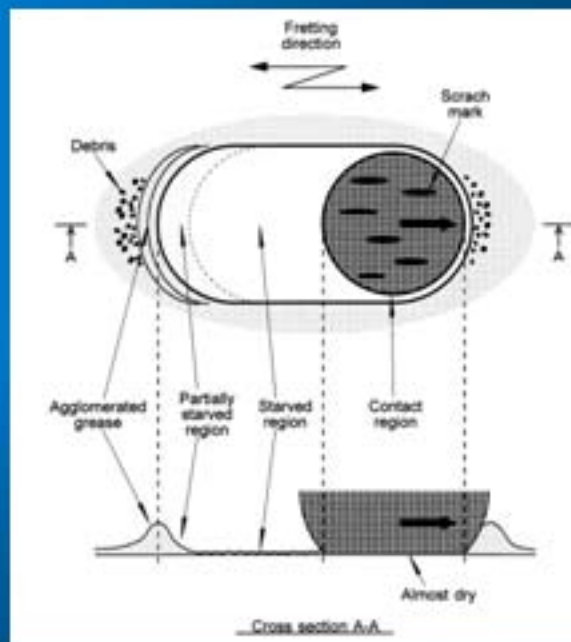
(iii)  $10^5$  cycles  
(c)  $G=4 mm^3$

Direct observation of fretted surfaces

# Possible mechanism

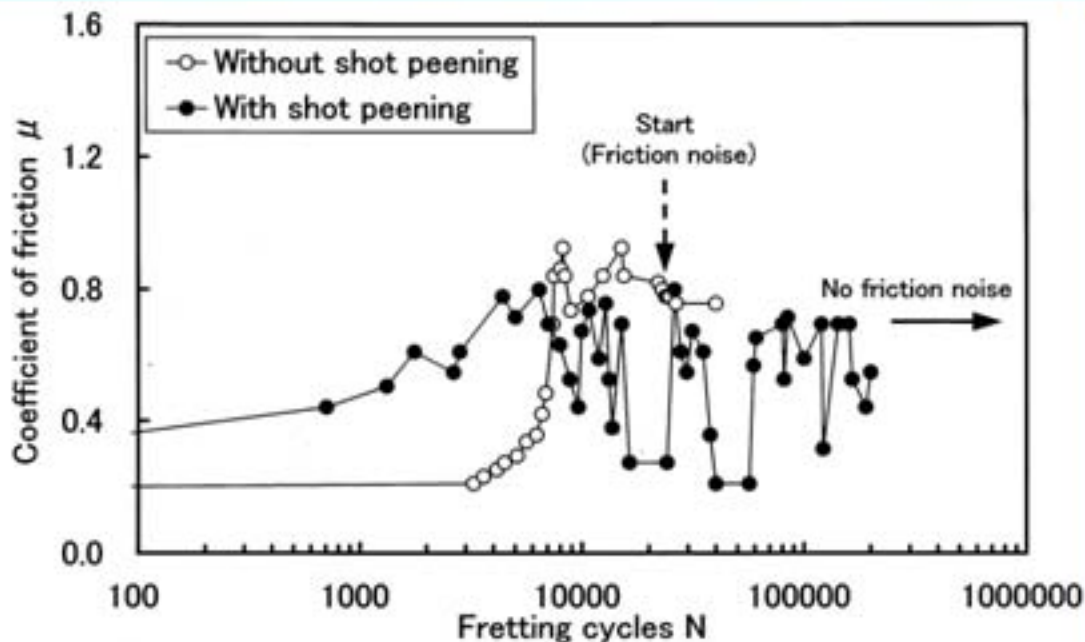


(a) Sufficient amount of grease



(b) Small amount of grease

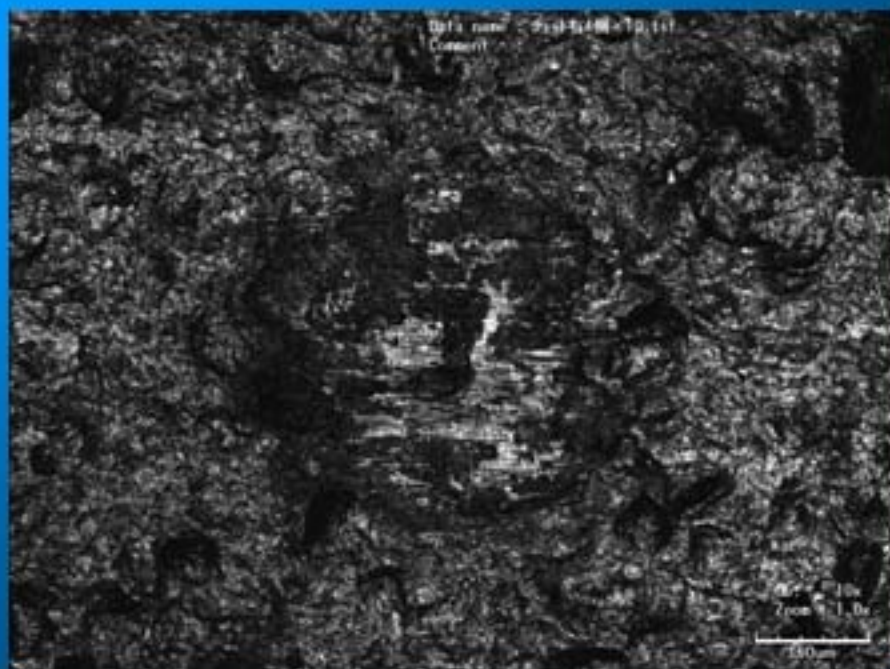
## Effect of shot peening



( $S=65\text{ }\mu\text{m}$ ,  $G=6\text{ }\mu\text{m}$ )



## Observation of wear scar with shot peening



(S = 65  $\mu$ m, G = 6  $\mu$ m)

(Shot condition : 0.6 mm steel ball, air type pressure = 0.3 MPa,  
120sec, arc height = 0.6 mmA, coverage = over 100 %)



## Brief Conclusions (3)

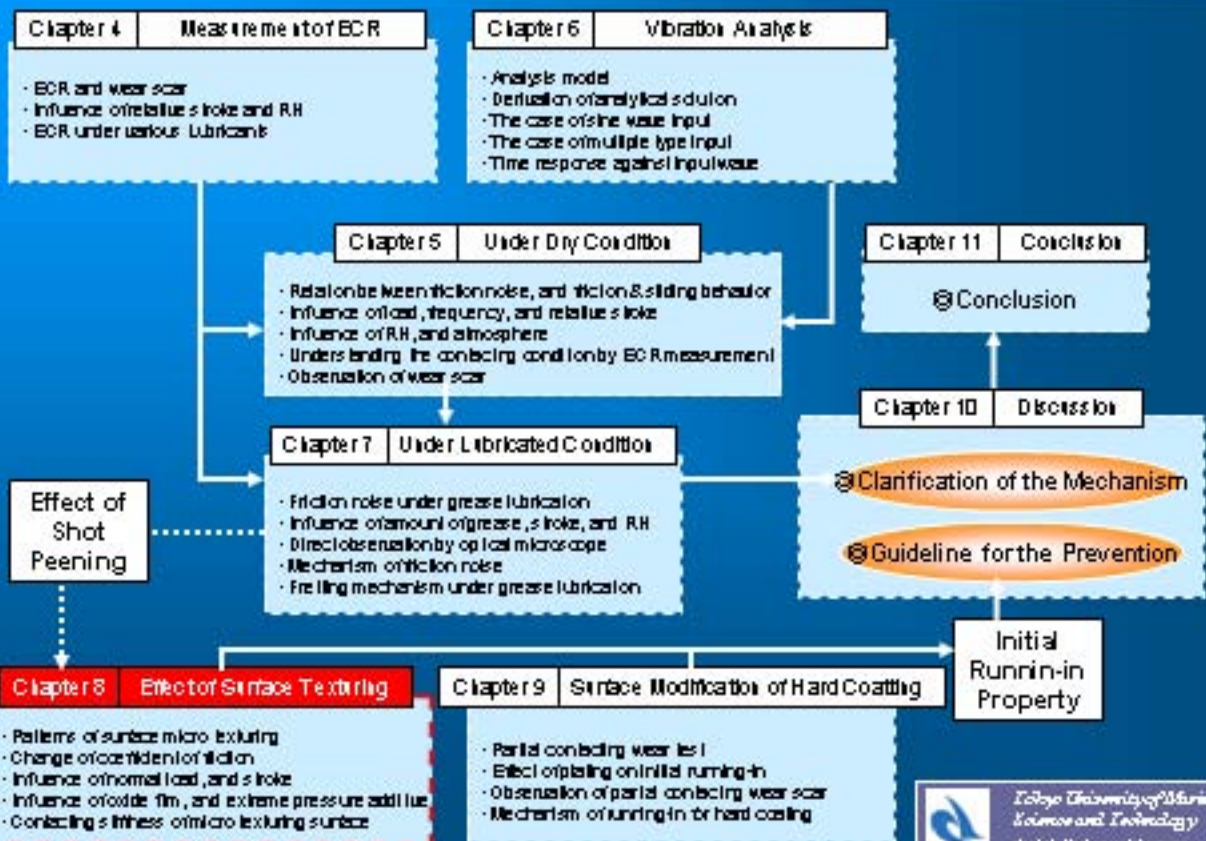
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1. The generation of friction noise under grease lubricated condition is greatly affected by the amount of grease supplied and fretting stroke.
2. In the case of a small amount of grease, friction noise similar to that of non-lubricated fretting generates, because once the grease is expelled from the contacting surfaces, it cannot be supplied from around the fretted contact. The worn surfaces are basically the same as those of non-lubricated fretting.
3. In the case of sufficient amount of grease, the friction noise never generated during whole fretting. Because the grease around the fretted surfaces is gradually supplied into the contacting surfaces with fretting action. The coefficient of friction  $\mu$  is constantly low and fretting wear hardly occurs.
4. Very small holes lying on fretted surfaces such as those by shot peening from "oil pools", and are effective to prevent the friction noise. They gradually supply the lubricants to the fretting surfaces.



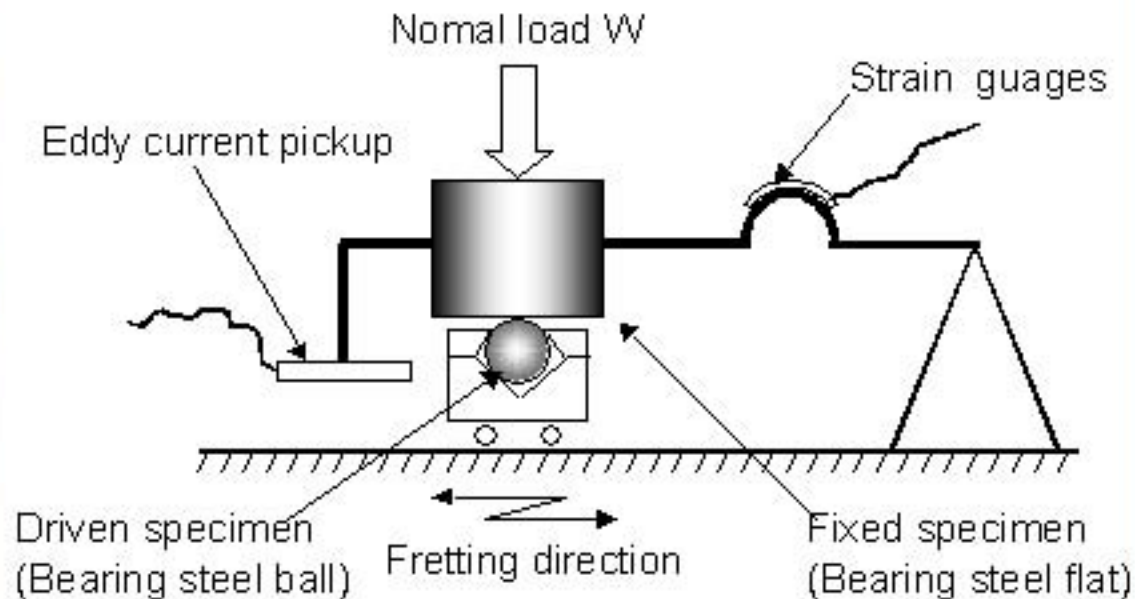


# Composition of this Study

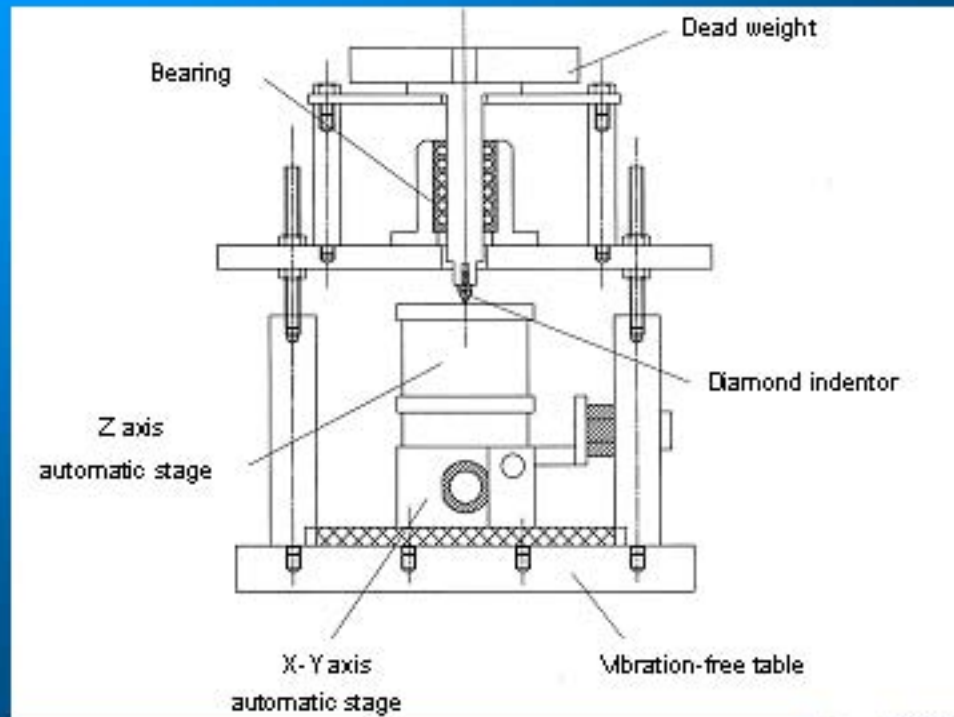




## Overview of fretting apparatus

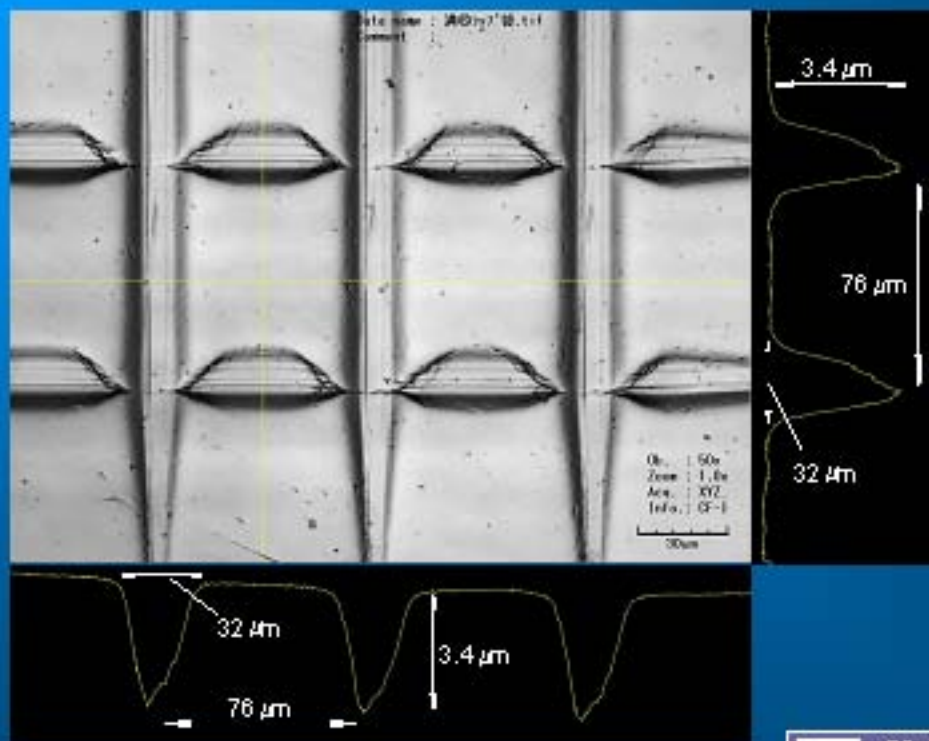


# Overview of surface micro fabrication apparatus





# Laser microscopic image of micro texturing surface (Groove pattern)

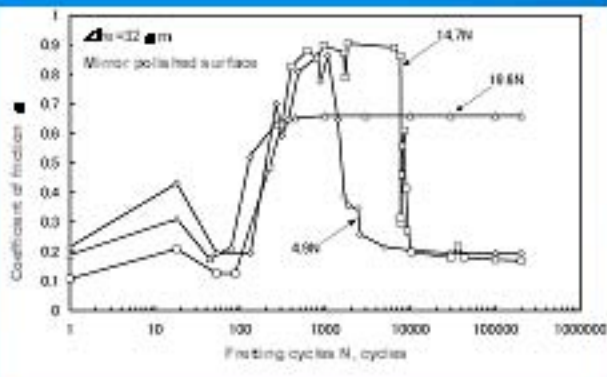


## Experimental condition

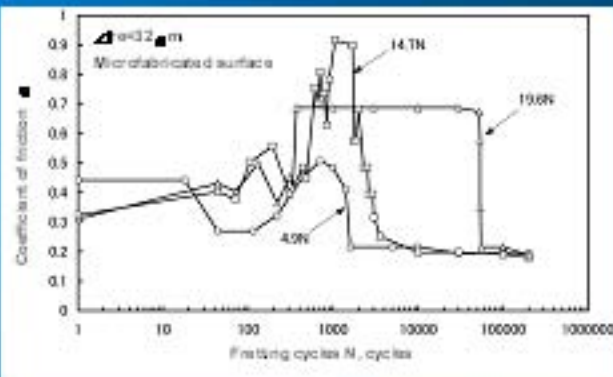
Specimen	Fixed	Bearing steel flat (Hv760), $\phi 20 \times 20\text{mm}$
	Driven	Bearing steel ball (Hv760), $\phi 9.525\text{mm}$
Configuration	Point contact (flat/sphere)	
Relative stroke	12~215 $\mu\text{m}$	
Normal load	4.9~22.1N	
Atmosphere	In air, oil lubrication	
Lubricants	360 neutral oil, Kinematic viscosity; 74.72cSt@40°C, 9.26cSt@100°C	
Fretting cycles	$20 \times 10^4$ cycles	
Frequency	7.35Hz	
Temperature, humidity	$22 \pm 3^\circ\text{C}$ , $51 \pm 18\%$	



# Change in coefficient of friction $\mu$



(a) Mirror polished surface

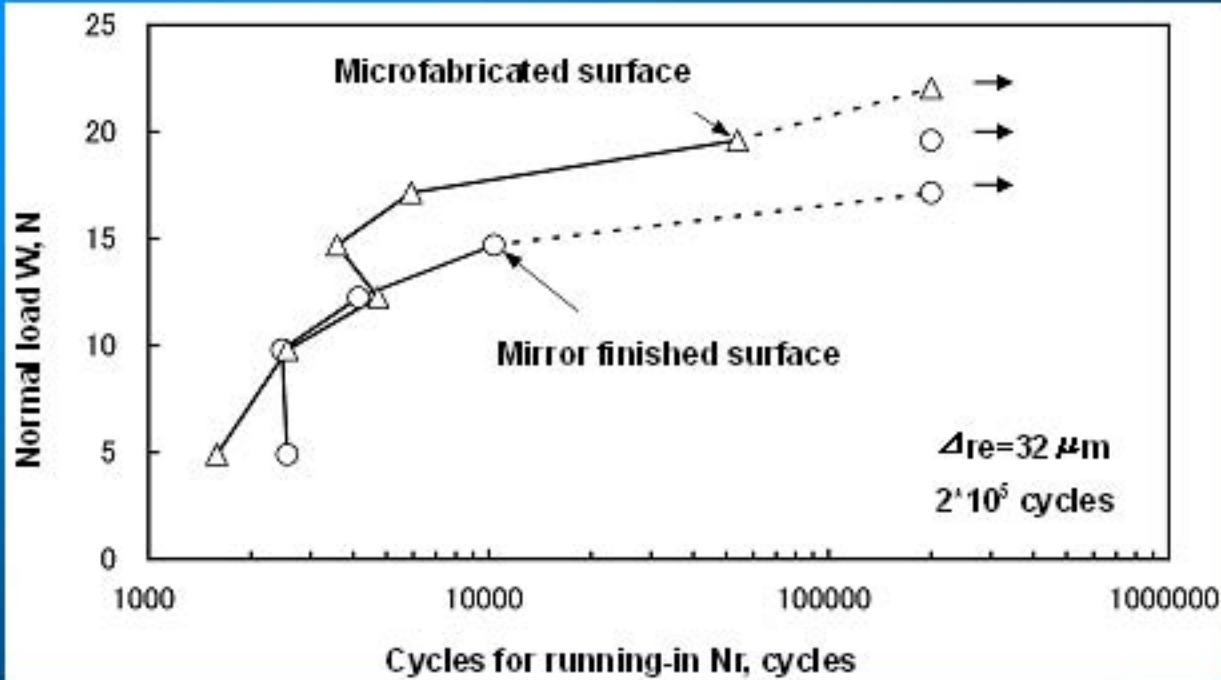


(b) Microfabricated surface

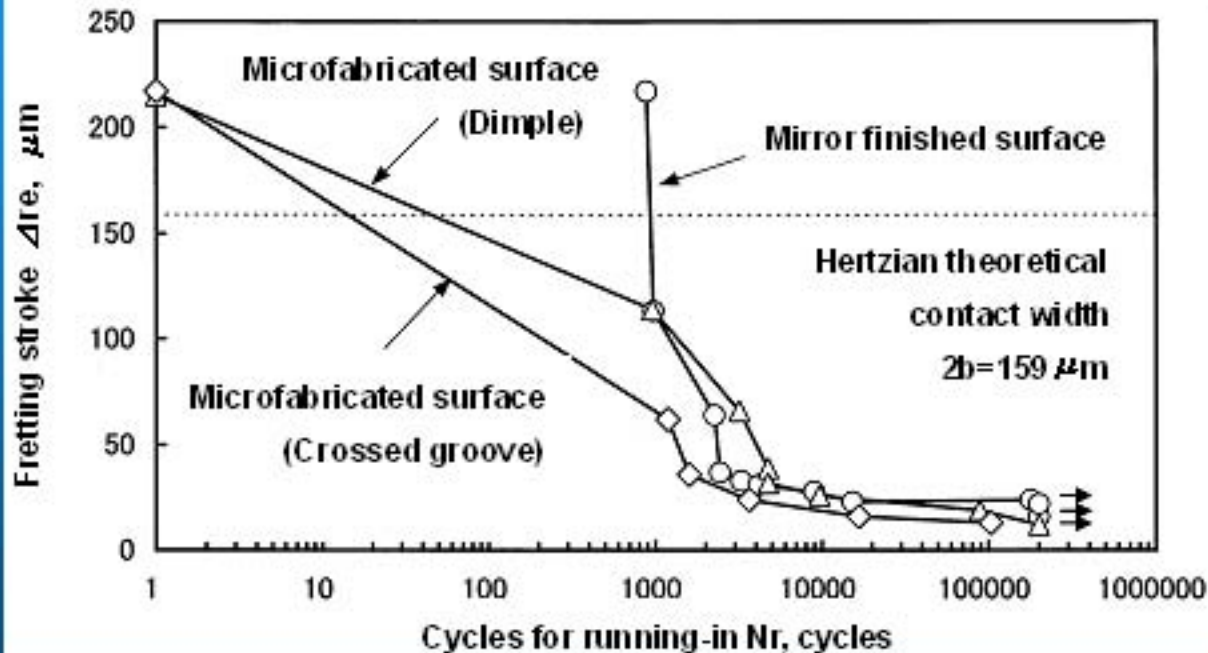




## *Influence of normal load $W$*



## Influence of fretting stroke $\Delta re$



( $W=12.3N$ ,  $2 \cdot 10^5$  cycles)



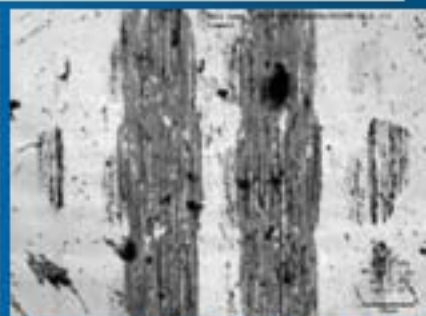
# Observation of fretted wear scars



(a) Mirror finished surface (half)



(c) Microfabricated surface (half)



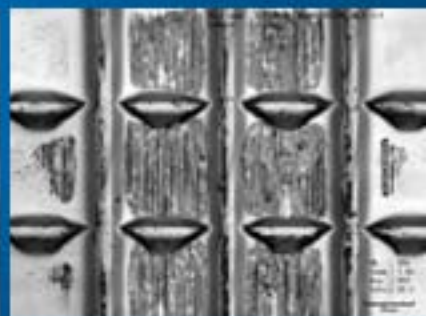
(e) Microfabricated surface (ball)



(b) Mirror finished surface (flat)  
(Wear scar width =  $143\text{ }\mu\text{m}$ )  
( $\Delta F_e = 36 \sim 39\text{ }\mu\text{m}$ ,  $W = 12.3\text{N}$ )

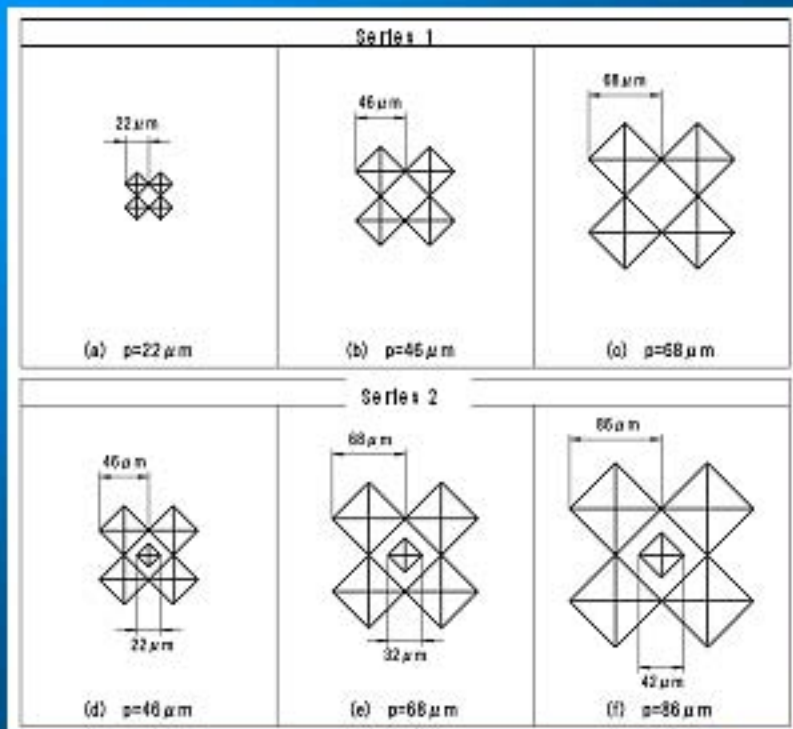


(d) Microfabricated surface (flat)  
(Wear scar width =  $197\text{ }\mu\text{m}$ )

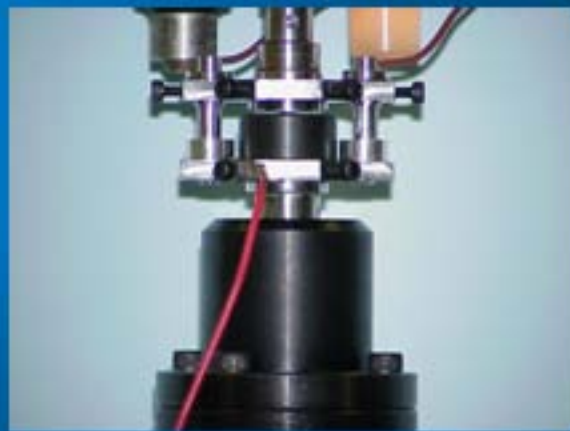
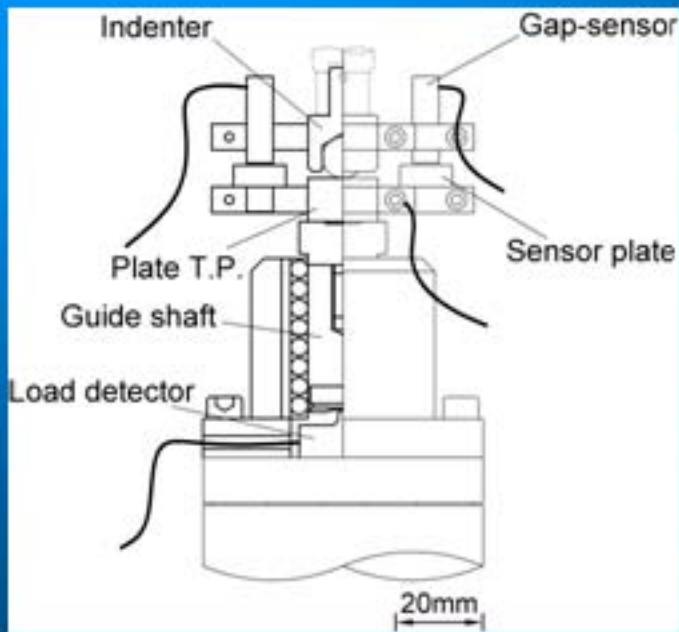


(f) Microfabricated surface (flat)  
(Wear scar width =  $231\text{ }\mu\text{m}$ )

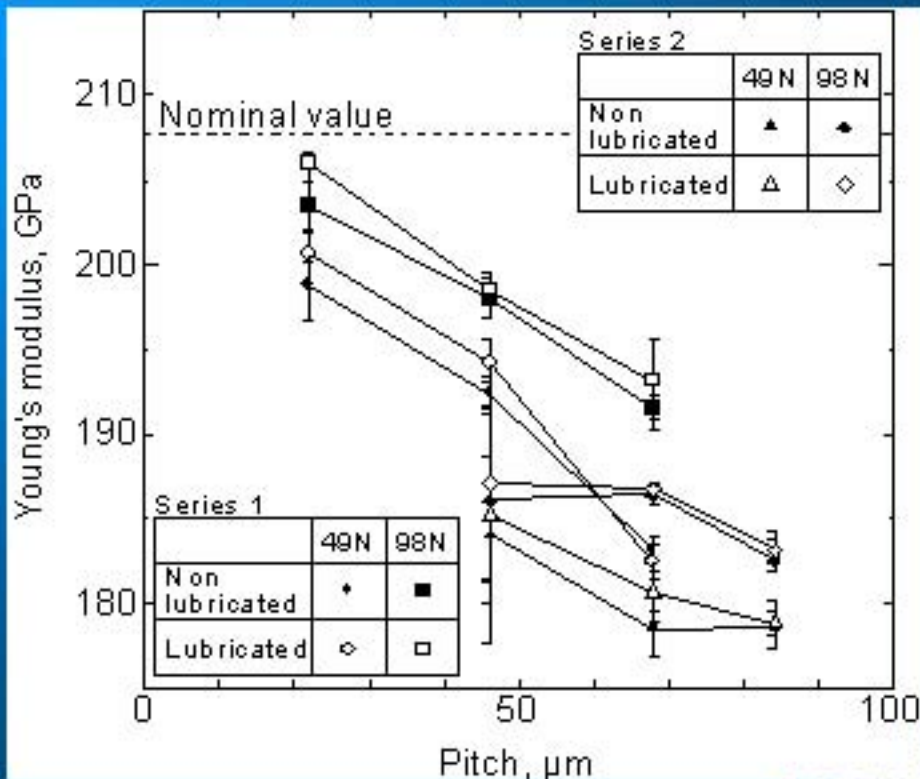
# Patterns of micro texturing



# *Schematic illustration of Young's modulus measuring apparatus*



# Contacting stiffness of micro texturing surface





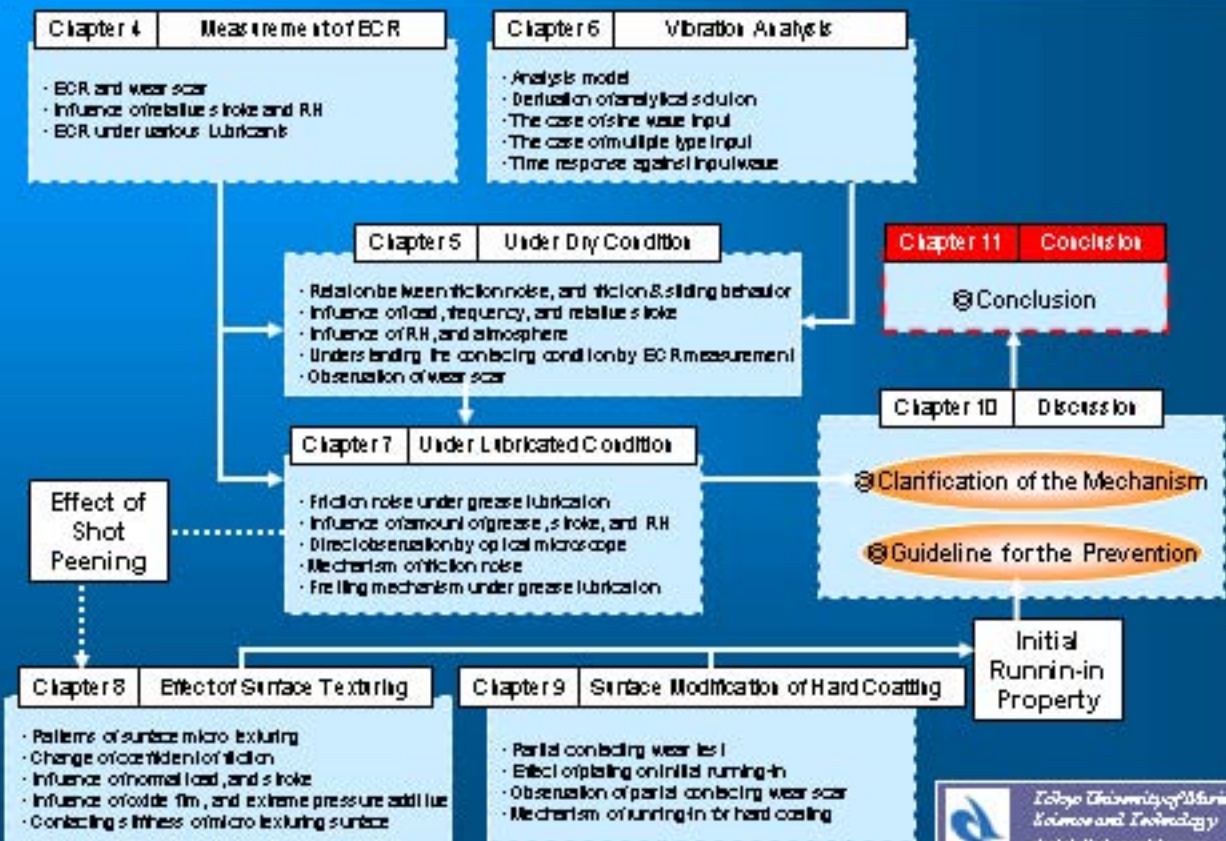
## Brief Conclusions (4)

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1. The micro texturing surface has an effect to accelerate the initial running-in process compared with that of the mirror finished one.
2. The contacting stiffness of the micro texturing surface is low compared to that of the mirror finished one, and the contact region is larger. The lubricating oil existing in the dimples bears a portion of the contact load.
3. The contact pressure around the dimples, that is, in the plateau regions, is high, and it is still higher at the edge of the contact region. These pressure are higher than the maximum Hertzian contact pressure for the mirror finished surface at the center of the contact region.



# Composition of this Study



## *Conclusions I*

### *Mechanism of friction noise*

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1. Under the dry condition, certain cycles of fretting are needed to generate friction noise, and there is a close relationship between the generation of friction noise and wear process.
2. When the wear debris is accumulated in the contacting surfaces with the wear progression, types of real contacting point become diverse, and friction behavior easily becomes changeable.
3. When the phenomenon of drastic reduction of  $\mu$  occurs, it becomes "trigger", and friction noise generates.

1. Under the grease lubricated condition, in the case of sufficient amount of grease, friction noise never generated, however, in the case of a small amount of grease, it cannot be supplied from around the fretted contact, and then it becomes the same as that under the dry condition, finally friction noise generates.
2. The mechanism of friction noise under the lubricated condition is basically the same as that under the dry condition.





1. It takes constant lubricants in the contacting surfaces to prevent the friction noise under the grease lubricated fretting . The effectiveness of "shot peening" was confirmed as one of the example to actualize it.
2. "Micro pools", or "Micro grooves" formation on the surface is effective to prevent the fretting damage, and its effect results in the prevention of friction noise.



# Questions and Answers

